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Wood Finger-Joint Strength as Function of Finger Length and Slope Positioning of Tips

Besnik Habipi, Dritan Ajdinaj

Abstract— **A study was carried out to analyse the relation of slope positions of fingers tips and finger length with regard to bending strength of poplar (*Populus alba* L.) and silver fir (*Abies alba* Mill.) finger joints, bonded with polyvinyl adhesive. There were produced three finger lengths, 6, 10 and 14 mm, as well as four series for each finger length and species, with 16 test pieces for each series. The first one with tips in straight vertical line and three others with tips in slope direction, respectively with slope angle 10°, 20° and 30°, referring to the first one direction. With regard to fingers with tips in slope position were respected the same values of length and pitch. Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) of finger joints were measured according to norms ISO 13061-3 and ISO 13061-4. Results showed that static bending strength was strongly influenced by the length of finger. For longer fingers the strength resulted higher. This relationship was referred to the rate finger length/pitch from 1 to 2.3. With regard to position of fingers tips, the angle 10° showed the best performance for all three finger length taking into account. By the other hand, modulus of elasticity wasn't affected in a distinct manner neither by the slope angle of fingers tips position, nor by the finger length. We can say that "scarf-finger joint" with slope angle of 10°, has a better performance with regard to MOR in static bending strength, presenting so a good opportunity for industrial application.**

Index Terms— **bending strength, finger-joint, finger length, slope angle, wood.**

I. INTRODUCTION

Finger-joint is one of the strongest wood joints used for structural and non structural applications. It is a decisive element for production of glued-laminated timber, I-joists, wall studs and trusses as well as solid wood based panels used for furniture production. It is commonly classified by wood specialists as high quality product, because of its desirable properties such as straightness, dimensional stability, and interchangeability with un-jointed lumber and unlimited length.

The strength of finger-joint depends on several wood-related factors such as species, density, natural defects as well as on processing parameters such as moisture content and temperature of lumber, finger geometry, machining process parameters, assembly pressure, curing time, adhesive type and pre-treatment of wood [1]-[7].

Finger-joint geometry is one of the most important variables determining joint strength [8]-[10]. There are four parameters which describe the finger's profile geometry, teeth length, pitch, fingertip and slope angle.

Besnik Habipi, Department of Wood Industry, Agricultural University of Tirana, Tirana, Albania, +355672018993.

Dritan Ajdinaj, Department of Wood Industry, Agricultural University of Tirana, Tirana, Albania, +355682097866.

Finger-joint profile is the governing factor in determining joint strength among wood density, adhesive, finger-joint profile and end pressure [11]. Other studies have shown that the finger length is not a critical factor in determining the joint strength. Instead, the critical finger profile parameters to achieve high strength are found to be slope and tip sharpness. Literature indicates that the tensile strength of finger-joined lumber increases with decreasing slope and increasing tip sharpness [11].

Walford examined the effect of finger length on the tensile strength of radiata pine lumber intended for both non-structural and structural applications. The finger length used in his study ranged from 3.5 mm to 16 mm. He found that shorter joints are slightly stronger than longer ones but require greater precision in manufacture. As well as finger-joined lumber made of low density wood tends to fail in wood, but those made of high density wood fail in joints in which glueline strength governs. Also he found that a small tip improves the strength of joints [12].

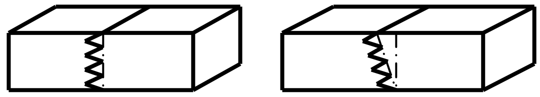
With regard to structural finger joints of Douglas-fir wood, the tensile strength parallel to the grain for 38 mm fingers results 43% higher than 22 mm ones, while the fatigue strength is almost the same [13]. Other studies with softwoods have found that the tensile strength of lumber joined with a 21 mm long finger profile presents a significantly lower value than those with 18 and 24 mm finger profile groups by 11.3 and 8.5%, respectively, due to the wide finger tips [14].

For broadleaves of low to medium density destined for structural products, the optimal finger's length appears to be 18 mm [15], while the slope 1 in 16 to 1 in 20 produces elevate joint strength comparable to clear wood strength when is properly bonded [16]. Other studies on finger joints from high density hardwoods like beech and oak, confirm that the highest bending strength (MOR) is obtained for the highest finger lengths [7], [17].

Between pitch and tip width, the last one results as a geometrical parameter of great importance in strength of finger-joint. Smaller to be the tip width, stronger is the finger-joint. The recommended tip width is from 0.5 to 0.7 mm [18]. If fingers length becomes larger without increasing fingers pitch, the strength of connection increases, but the best results are obtained for values of length/pitch from 4 to 5 [19]. Gaps between fingers tips and bases appear as necessity for accumulation of excessive adhesive. According to the German Standard 68140-1, this gap varies in 0.03 of finger's length [20]. Anyway, many authors have found that modulus of elasticity (MOE) and sometimes and the ultimate tensile strength (UTS), are not significantly influenced by finger's profile geometry [1], [15], [17], [21].

Many studies have showed that wood species with density higher than 700 kg/m^3 give uncertain performance, while those with lower density appear to be more predictable in their performance [22].

In a finger joint connection, finger tips are positioned in a straight line oriented vertically regarding to edges of wood pieces. It means that two pieces are in contact between them through the shorter contact vector (figure 1).



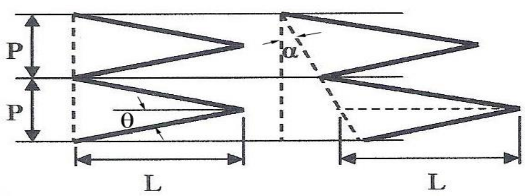
vertical position slope position

Figure 1: Position of finger tips

Taking into account this disadvantage, a study is carried out to analyse the relation of slope positions of fingers tips and finger length with regard to bending strength of poplar (*Populus alba* L.) and silver fir (*Abies alba* Mill.) finger joints, bonded with polyvinyl adhesive.
It aims to give information about opportunities for production and application of a better quality and performance of wooden products and their structures. The selection of wood species is conditioned by massive usage of fir as raw material for wooden constructions and processing industry as well as by the growing interest in poplar, taking into account that this wood presents good opportunities for application, because of its low cost and weight [23].

II. Materials and Methods

Wood material for production of samples was selected from pieces of kiln dried poplar and silver fir boards, with moisture content from 10 to 12%. From selected pieces were sawn blocks without deformations or structure defects with dimensions of cross-section 5×6 cm, and various lengths. Fingers profiles were produced with edged tips on one head of each block by means of a spindle moulder. There were produced three finger lengths (L), 6, 10 and 14 mm, as well as four series for each finger length and species, with 16 test pieces for each series. The first one with tips in straight vertical line and three others with tips in slope direction, respectively with slope angle (α) 10°, 20° and 30°, referring to the first one direction (figure 1). With regard to fingers with tips in slope position were respected the same values of length and pitch (P).
The geometric profile of cutter heads (knifes), which means the geometric profiles of fingers are shown in Figure 2. The defining of data tests was carried out, in order to compare results and essential parameter that affected on bending strength (Table 1).



tips in vertical position tips in slope position

Figure 2: Geometric profile of fingers

Table 1: Tests data variables

Code		L	P	Θ	α
Fir	Poplar	[mm]	[mm]	[°]	[°]
F6 - 0°	P6 - 0°	6	6	17	0
F6 - 10°	P6 - 10°	6	6	-	10
F6 - 20°	P6 - 20°	6	6	-	20
F6 - 30°	P6 - 30°	6	6	-	30
F10 - 0°	P10 - 0°	10	6	17	0
F10 - 10°	P10 - 10°	10	6	-	10
F10 - 20°	P10 - 20°	10	6	-	20
F10 - 30°	P10 - 30°	10	6	-	30
F14 - 0°	P14 - 0°	14	6	17	0
F14 - 10°	P14 - 10°	14	6	-	10
F14 - 20°	P14 - 20°	14	6	-	20
F14 - 30°	P14 - 30°	14	6	-	30

Following fingers production and combination of blocks two by two, a PVA D1 glue (Neon, ALBANIA) was applied on one profiled head by brush. The quantity of glue was referred to industrial application 170÷240 [gr/m^2], resulting in 2.5÷2.8 [gr.] per piece. It was verified by weighing the pieces before and after application of glue. Then, the blocks couples were pressured manually by means of hand grip vices for a period of 24 hours. With regard to adhesive and pressure application, devices and techniques used in the study were typically for handicraft and small scale production, which has given the biggest share of finger-joint production in Albania.
After, the jointed blocks were cut and planed to final dimensions 20×20×320 mm, to produce bending strength samples according to the standards ISO 13061-3 and ISO 13061-4 [24], [25].
The samples were conditioned to reach equilibrium moisture content around to 12%, and were tested by means of mechanical testing machine (Controlab, FRANCE). Modulus of rupture (MOR) and Modulus of elasticity (MOE) of joints were calculated in N/mm^2 according to standards mentioned above as follows:

$$MOR = \frac{3P_{\max} \times l}{2bh^2} \tag{1}$$

$$MOE = \frac{l^3 \times \Delta P}{4bh^3 \times \Delta y} \tag{2}$$

where P_{max} was the breaking load in newtons (N), l was the distance between the centres of supports in millimetres (mm), b was the breadth of the test piece in (mm), h was the height of the test piece in (mm), ΔP was the difference between respective loads of two points selected on the linear section of load-deformation graphic in (N), and Δy was the relative increment of deflections in bending in (mm).
After testing, the density of woods was measured according to the standard ISO 13061-2, using pieces provided by destroyed samples [26].

III. Results

Mean values of modulus of rupture (MOR) and modulus of elasticity (MOE), together with respective standard deviations, measured in static bending tests are shown respectively for poplar wood in Table 2 and for silver fir wood in Table 3.

Table 2: Results of MOR and MOE of poplar wood

CODE	MOR [N/mm^2]	Stand. Dev.	MOE [N/mm^2]	Stand. Dev.

P6 - 0°	23.79	4.47	11538.23	1076.39
P6 - 10°	25.77	4.18	10617.56	1128.44
P6 - 20°	25.62	3.73	12216.15	981.47
P6 - 30°	24.13	3.85	11784.44	963.84
P10 - 0°	26.77	4.14	10736.13	1247.10
P10 - 10°	29.16	3.89	12217.55	1024.63
P10 - 20°	28.22	4.46	11761.36	968.25
P10 - 30°	28.34	4.37	9981.71	1162.75
P14 - 0°	30.41	3.61	10217.62	1133.64
P14 - 10°	33.46	4.14	9733.15	1221.18
P14 - 20°	31.25	4.52	11672.34	1016.53
P14 - 30°	29.73	4.08	10186.98	973.88

Table 3: Results of MOR and MOE of silver fir wood

CODE	MOR [N/mm^2]	Stand. Dev.	MOE [N/mm^2]	Stand. Dev.
F6-0°	28.36	4.17	10812.60	981.48
F6-10°	30.87	3.95	11363.91	1167.31
F6-20°	31.36	4.07	10618.34	1092.16
F6-30°	29.44	3.68	12819.83	974.19
F10-0°	34.22	3.17	11643.24	1016.77
F10-10°	37.63	4.23	13271.66	1214.88
F10-20°	35.58	3.87	11558.42	966.37
F10-30°	35.85	4.46	11437.83	1065.72
F14-0°	36.51	3.84	11236.44	1126.13
F14-10°	39.17	3.63	10444.65	1268.58
F14-20°	37.34	4.13	12012.73	1294.14
F14-30°	35.85	3.88	11465.54	1092.46

Mean value of the density of poplar and fir wood used in our study resulted 0.48 g/cm^3 and 0.45 g/cm^3, with standard deviations respectively 0.037 and 0.052.

IV. Discussion

From examination of results can be noted that bending strength of both species was influenced by the slope of finger tips as well as by finger length.

In figures 1&2 are shown changes in % of MOR values respectively for poplar and silver fir wood, referring to vertical tips position (0°) value, with regard to three finger lengths, 6 mm, 10 mm and 14 mm.

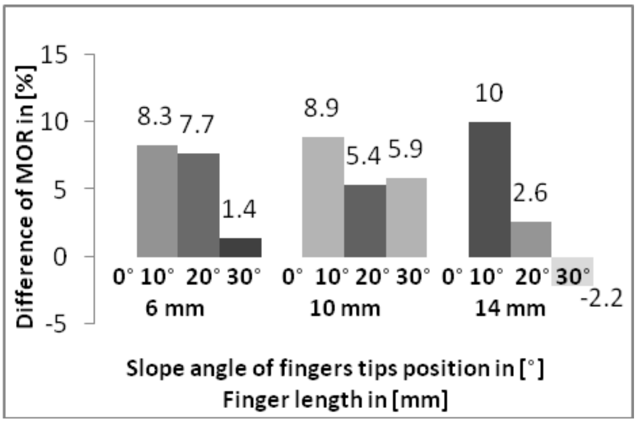


Figure 1: Differences of MOR values for poplar wood referring to 0° MOR value, for three finger lengths

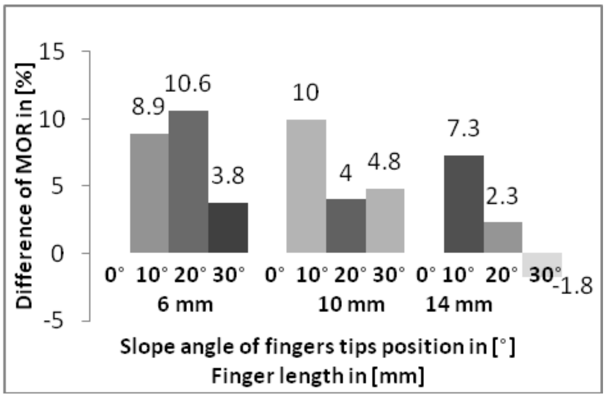


Figure 2: Differences of MOR values for silver fir wood referring to 0° MOR value, for three finger lengths

It seems that MOR of both species was decreased for 14 mm finger length while slope angle was increased from 10° to 30°. The 10° presented the highest MOR values for both species and for the three finger lengths, except of 20° slope and 6 mm finger length of silver fir wood, which was 1.7% higher than the 10° MOR value.

In figures 3&4 are shown changes in % of MOE values respectively for poplar and silver fir wood, referring to vertical tips position (0°) value, with regard to three finger lengths, 6 mm, 10 mm and 14 mm.

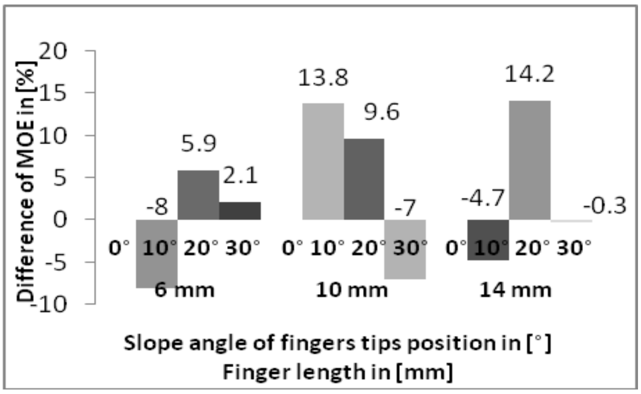


Figure 3: Differences of MOE values for poplar wood referring to 0° MOE value, for three finger lengths

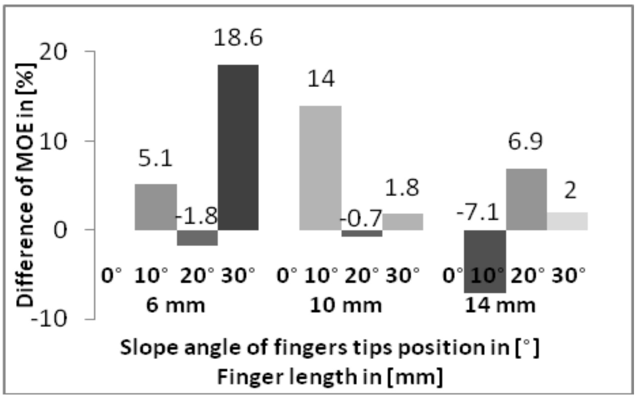


Figure 4: Differences of MOE values for silver fir wood referring to 0° MOE value, for three finger lengths

Analysing two graphs above was clear appeared that modulus of elasticity (MOE) wasn't affected in a distinct manner by the slope angle of fingers tips position.

In figures 5&6 are shown changes in % of MOR values respectively for poplar and silver fir wood, referring to 6 mm

finger length value, with regard to four position angels of finger tips.

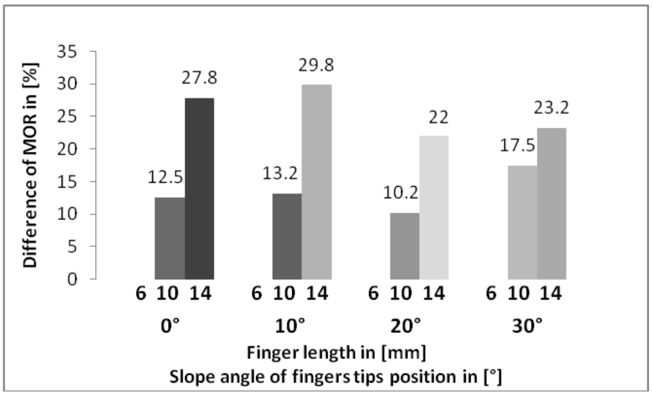


Figure 5: Differences of MOR values for poplar wood referring to 6 mm finger length MOR value, for four position angels of finger tips

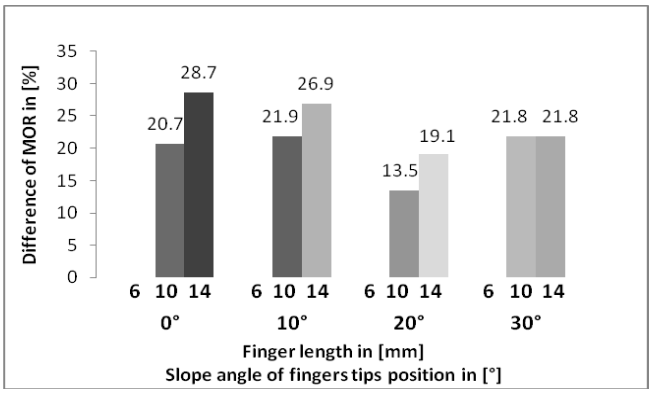


Figure 6: Differences of MOR values for silver fir wood referring to 6 mm finger length MOR value, for four position angels of finger tips

Analyse of MOR values showed that between finger length and bending strength, for both wood species, exist a positive correlation, apart from angle of finger tips position. For poplar wood this correlation is stronger than silver fir wood. Anyway, the rate finger length/pitch must be taken in consideration. It is known that the best results are obtained for values of this rate from 4 to 5 [19].

In figures 7&8 are shown changes in % of MOE values respectively for poplar and silver fir wood, referring to 6 mm finger length value, with regard to four position angels of finger tips.

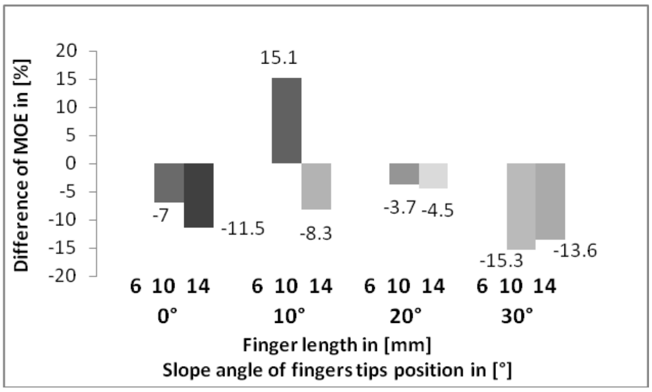


Figure 7: Differences of MOE values for poplar wood referring to 6 mm finger length MOE value, for four position angels of finger tips

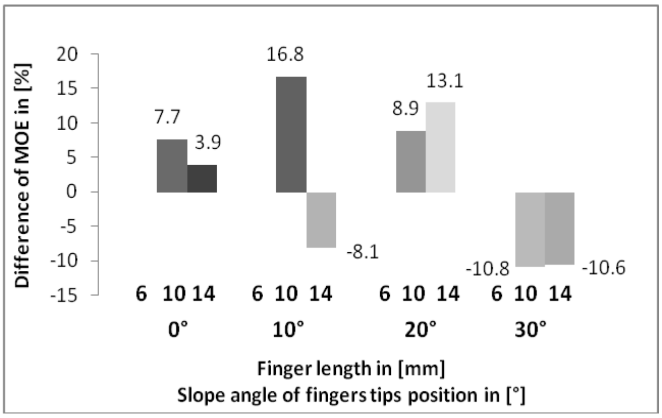


Figure 8: Differences of MOE values for silver fir wood referring to 6 mm finger length MOE value, for four position angels of finger tips

As before, MOE wasn't affected in a distinct manner by the finger length, regardless the slope angle of fingers tips position.

V. Conclusions

Historically, finger-joint was developed as a further development of scarf joint, which was formed by cutting a slope to the ends, thus exposing wood that approaches side grain. At slope from 1 in 10 to 1 in 20 was found that scarf joint efficiency ranged from 85 to 95% of clear wood tensile strength [27]. However, scarf joints presented some deficiencies regarding to waste of wood and accuracy in machining, which caused their replacement by finger joint.

Finger joint is now the dominant type of end joint and its mechanical performance is influenced, among the others, and by configuration of fingers. In a finger-joint finger tips are positioned in a straight line oriented vertically regarding to edges of wood pieces, what it means that two pieces are in contact through the shorter contact vector.

To combine the advantages of scarf joint with finger one, a study was carried out to analyse the relation of slope positions of fingers tips and finger length with regard to bending strength of poplar (*Populus alba* L.) and silver fir (*Abies alba* Mill.) finger joints, bonded with polyvinyl adhesive. Results showed that static bending strength was strongly influenced by the length of finger. For longer fingers the strength resulted higher. This relationship was referred to the rate finger length/pitch from 1 to 2.3. With regard to position of fingers, the study showed that slope position gave a better result that vertical one, except of 30° slope angle of 14 mm finger length, which produced lower strength. The angle 10° showed the best performance for all three finger length taking into account. By the other hand, modulus of elasticity wasn't affected in a distinct manner neither by the slope angle of fingers tips position, nor by the finger length.

As a conclusion we can say that "scarf-finger joint" with slope angle of 10°, has a better performance with regard to modulus of rupture in static bending strength, presenting so a good opportunity for industrial application.

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B. Habipi is a student presently pursuing Ph.D in Wood Department Industry of Faculty of Forestry Sciences, Tirana, Albania. His field of research includes mechanical processing of wood as well as technologies of wood gluing. He has published six papers in International and National Conferences.

D. Ajdinaj is Professor in Wood Department Industry of Faculty of Forestry Sciences, Tirana, Albania. His field of research includes mechanical processing of wood, production of wood based panels as well as technologies of wood gluing. He has published more than 25 papers in International and National Conferences.